ONSHORE-OFFSHORE SAND TRANSPORT ON DEL MONTE BEACH, CALIFORNIA

John David Williamson

NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

ONSHORE-OFFSHORE SAND TRANSPORT

ON

DEL MONTE BEACH, CALIFORNIA

by

John David Williamson

Thesis Advisor: Warren C. Thompson

September 1972

Onshore-Offshore Sand Transport

on

Del Monte Beach, California

by

John David Williamson
Ensign, United States Navy
B.S., University of Oklahoma, 1971

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL
September 1972

ABSTRACT

Daily sand volume transport values were calculated for a selected beach profile during a two-month period. Wave data were recorded continuously directly seaward of the profile. Tide effects were largely filtered out by use of a lunar day (24.8 hour) sampling interval.

Offshore sand transport occurred in isolated events of one to two-day duration, and had a maximum value of 132.5 cubic feet/foot of beach width/lunar day. Onshore transport occurred over longer intervals of up to seven days, and had a maximum value of 47.0 cubic feet/foot/day.

Onshore-offshore transport over a 24.8 hour period depends, to a first approximation, on the mean wave steepness incident upon the beach and the initial beach slope for the period. If the initial beach slope is greater (less) than the equilibrium slope associated with the existing wave conditions, or if the profile is initially at equilibrium and the wave steepness increases (decreases), sand will be moved offshore (onshore). The closer to equilibrium the beach is, the smaller the transports are.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

The author wishes to express his appreciation and thanks to Professor Warren C. Thompson who suggested the use of synoptic wave graphs in the analysis of the data, and whose many hours of patient assistance were invaluable in the completion of this investigation. The facilities of the W. R. Church Computer Center at the Naval Postgraduate School were utilized for data reduction and analysis.

I. INTRODUCTION

A. OBJECTIVE OF THE STUDY

Previous investigators have demonstrated that natural sand beaches on the open coast are sensitive to incident ocean waves, and that the observable portion of such beaches may change measurably over very short time intervals ranging from less than an hour to approximately one day, (Shepard and LaFond, 1940; Inman and Filloux, 1960; Strahler, 1964; Rohrbough, Koehr, and Thompson, 1964; Ingle, 1966; Harrison, et al., 1968; Haydock, 1969). Such changes in a beach profile are a consequence of onshore-offshore transport of sand by wave action, with the nature of these changes presumably being closely related to the character of the waves incident upon the beach. However, to the author's knowledge, only one quantitative relationship has been published (Thompson and Harlett, 1969) on the response of a natural beach to the incident waves.

The present investigation utilizes the beach-profile data gathered by Harlett (1967) in Monterey Bay, California. Whereas Harlett worked with beach profile changes, this study examines sand volume gains and losses. The beach-profile measurements used were made daily over a two-month period along a selected profile, and the waves incident upon the profile were recorded continuously during most of the period. The objectives of this study were: (1) to describe, on a

daily basis over the two-month period, the characteristic values of and the variation in the volumes of sand transported on and off the beach in a direction perpendicular to the shore, and (2) to relate this sand transport to the incident wave conditions.

B. DESCRIPTION OF THE BEACH

The beach profile examined in this study is located on Del Monte Beach in the southern end of Monterey Bay, California (Figures 1 - 4). Del Monte Beach is a long, unbroken, gently curving, sand beach backed by an inactive dune ridge. The shoreline is in dynamic equilibrium and has remained essentially in the same mean location since the earliest survey of 1851 (House Doc. No. 219, 1959).

The beach is quite uniform laterally and characteristically possesses a simple profile with no offshore bars. The slope at the mid-tide level is approximately 1:50. Seaward of the surf zone the bottom is smooth and slopes gently seaward with the bottom contours being parallel to the shoreline.

The material composing the exposed portion of the beach is a very well sorted, medium to fine, quartz-feldspar sand with a mean grain diameter of about 2ϕ. The textural properties of the sand, sampled daily across the beach face during the period of the field measurements, were found to be nearly constant (Harlett, 1967). Subdued cusps frequently occurred on the upper portion of the beach during the field study.

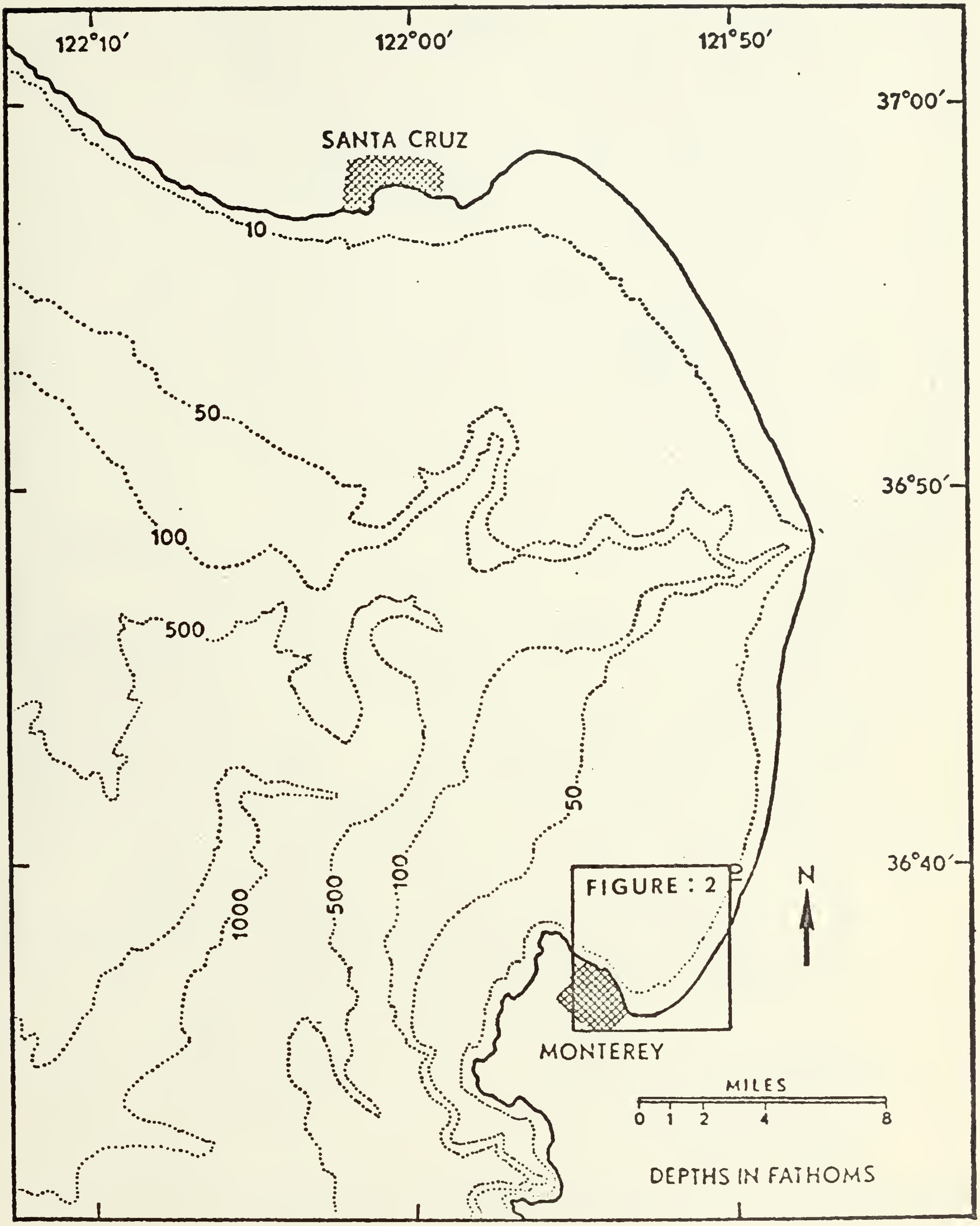


Figure 1: MONTEREY BAY, CALIFORNIA

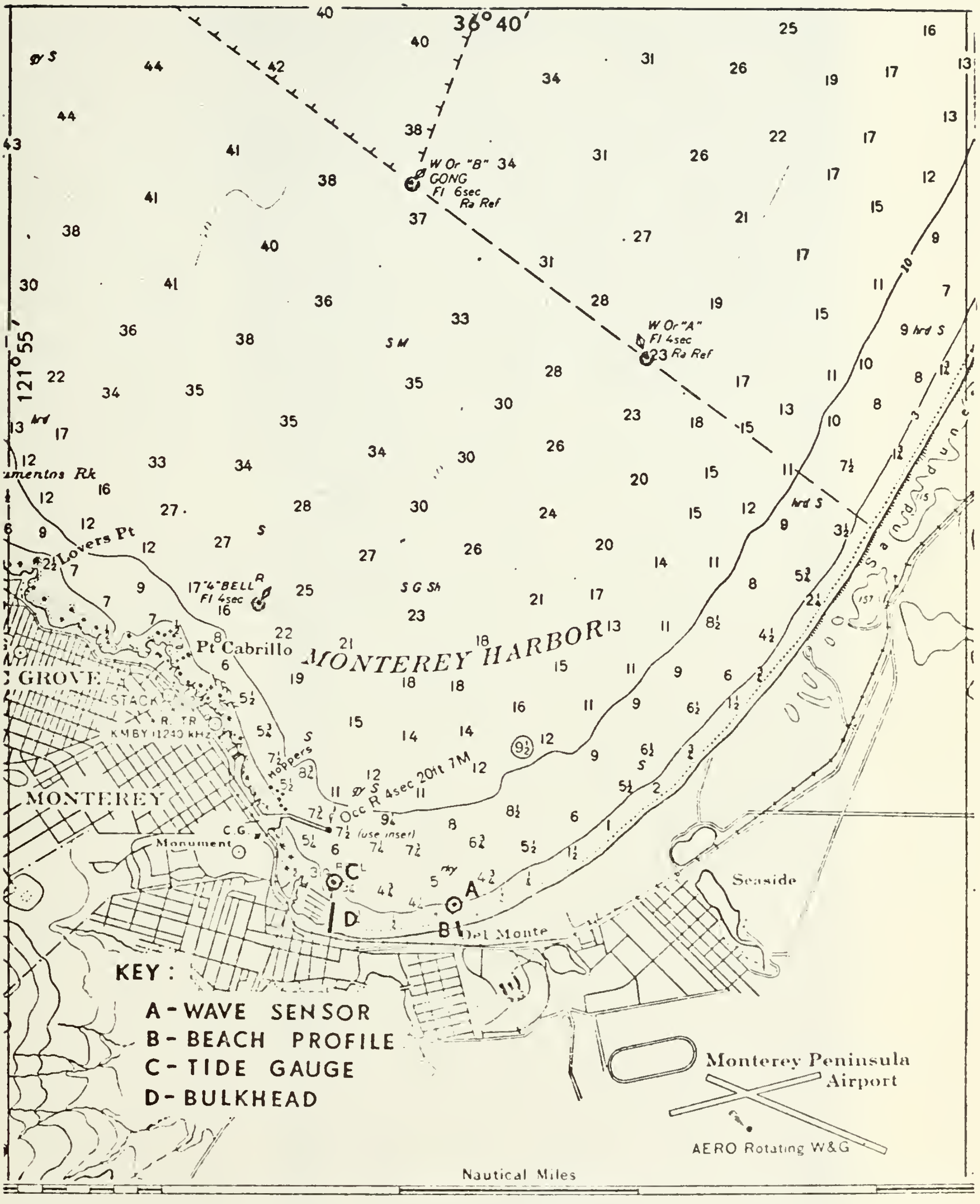


Figure 2: LOCATION OF BEACH PROFILE AND WAVE GAUGE

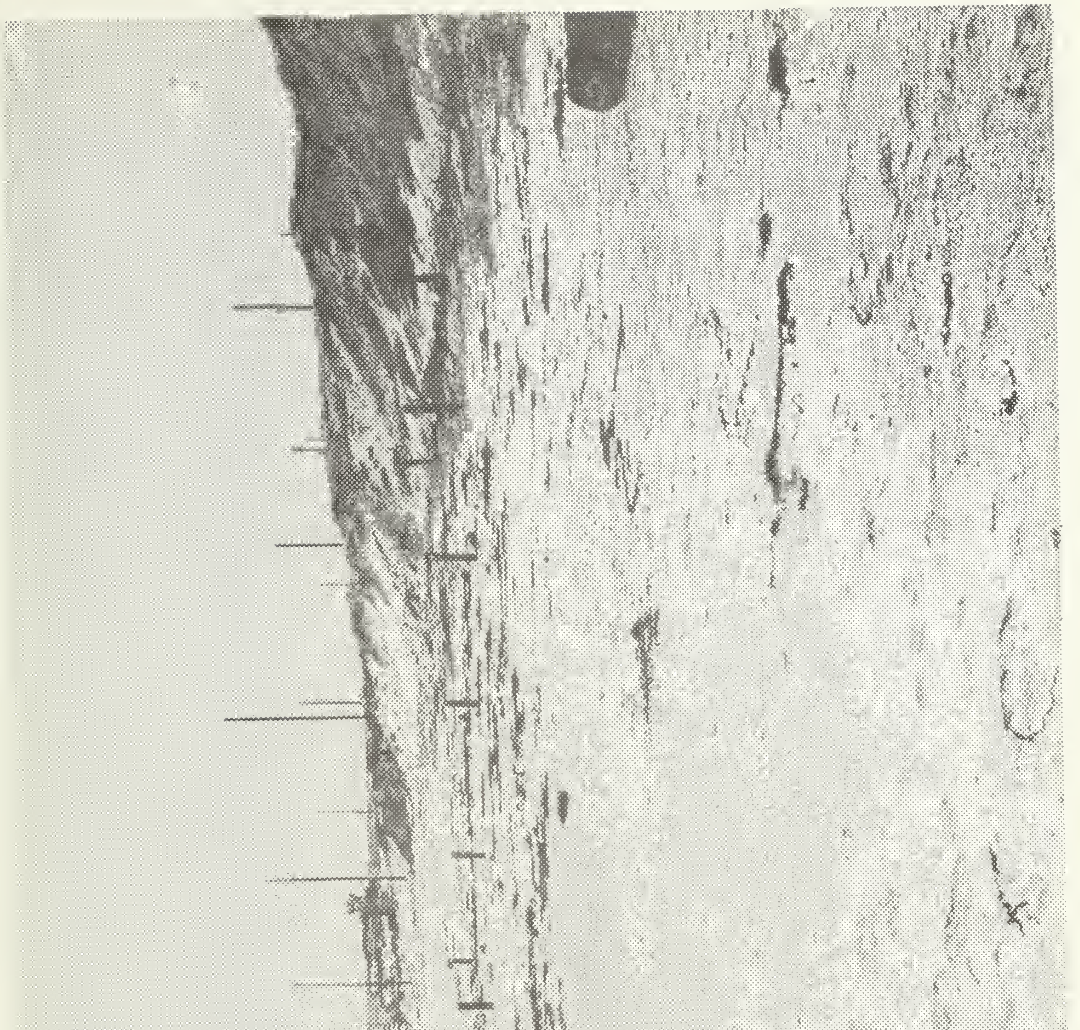


Figure 3: DEL MONTE BEACH PROFILE

Figure 4: SEAWARD PORTION OF PROFILE AND REFERENCE RAIL

The beach studied is protected by the Monterey Peninsula in such a manner that essentially all waves arriving on the beach from the open ocean are transformed by intense refraction to swell of low height and steepness (Figure 1). In addition, refraction is such that the waves arrive on the beach with their crests parallel or nearly parallel to shore. Plunging breakers with heights characteristically below three feet predominate.

Because of the very low to zero breaker angles characteristic of waves on Del Monte Beach, littoral drift is negligible. The absence of littoral drift is amply demonstrated by the fact that a littoral barrier about 1000 yards downcoast from the profile site has not caused accretion or erosion of the adjacent shoreline, and that the beach at the profile site has remained stable since its construction. The barrier in question is a solid bulkhead built in April 1962, which runs alongside Monterey Municipal Wharf No. 2 from the rear of the beach to a depth of about 18 feet. In view of the absence of littoral drift and the lateral uniformity of the beach, it was concluded that the changes observed in the profile of the beach involve only onshore-offshore transport of sand.

The tides in Monterey Bay, as for the entire Pacific Coast, are of the mixed type, and have an average diurnal range of 5.3 feet (MLLW to MHHW). The tidal datum for the coast is MLLW.

It is evident from this description that the beach under investigation is a natural laboratory where profile changes may be examined under relatively simple beach conditions and distinctive wave conditions. Accordingly, it appears that conditions are simple enough to expect that the observed onshore-offshore transport of sand can be correlated with the incident wave conditions.

C. FIELD AND OBSERVATIONAL SETUP

The beach and wave information utilized in this study were collected over the period from 1 February through 31 March, 1967. Sand-level measurements were made relative to a series of twenty permanently fixed railroad rails driven into the beach (Figures 3 and 4). The rails extend from the toe of the dunes at the rear of the beach, above the level of the highest normal wave runup, down to the lowest tide level, and are approximately ten feet apart. The elevation of the top of each rail above MLLW was measured by a leveling survey to 0.01 feet relative to benchmarks located in the immediate vicinity.

The profile measurements consist of daily sand levels measured at each rail on the beach reduced to an elevation above MLLW (tabulated in Harlett, 1967). These sand levels were measured with respect to the top of each rail using a graduated, T-shaped staff. The purpose of the T was to bridge the scour depressions that sometimes occurred around the rails, particularly on the lower portion of the beach. In making

a measurement, the horizontal bar of the T was oriented parallel to the beach contours. Sand-level measurements were made to the nearest millimeter and are considered accurate to 0.5 centimeters or approximately 0.015 feet.

As was mentioned earlier, the measurements were synchronized with the daylight occurrence of lower low water when observations could most conveniently be made and the beach was most exposed. This resulted in a standard sampling interval of approximately 24.8 hours or one lunar day. However, when the time of the low-tide observation, progressing approximately 50 minutes from one day to the next, occurred near sundown the next sampling was shifted ahead only 12.4 hours (one-half lunar day) to the morning low tide. Four such "half-intervals" are included in the period of observations, occurring on February 13, and every 15 days thereafter. Using these intervals of observations resulted in all but three of the sampling tides being the lower low tide of the day. The relation of the daily sampling times to the tides is shown in the lower curve of Figure 7.

Wave data were recorded continuously over most of the period covered by the beach study using a bottom-mounted, pressure-type wave sensor. The sensor was located about 700 feet directly seaward of the profile at a mean depth of about 30 feet. The resulting analog wave records were manually analyzed for significant height at the sensor depth and wave period, as described later.

II. BASIC CONSIDERATIONS

It should be noted at the outset that this investigation was based on some important initial considerations.

Several assumptions as to the character of beach changes with respect to changing wave parameters were made based on the results of wave-tank and field studies done by others and from examination of the data collected for this study. These assumptions are: (1) that real ocean waves having a specific set of properties will produce a characteristic equilibrium profile in the beach if they remain constant for a sufficient length of time, (2) a beach, therefore, will tend constantly to readjust its profile so as to approach the equilibrium profile associated with the momentarily prevailing wave conditions, and (3) the response of the beach profile to changing wave conditions to a first approximation is sufficiently rapid that the profile is fairly close to equilibrium at all times. The first two assumptions are amply supported by numerous laboratory and theoretical studies (Watts, 1954; Rector, 1954; Watts and Dearduff, 1954; Ippen and Eagleson, 1966; Nayak, 1970). The third assumption was adopted from Thompson and Harlett (1969) and allows the daily sand transports to be correlated with the wave conditions occurring over the same interval of time.

From these assumptions, it was concluded that if, at a given time, a beach is steeper (less steep) or at an elevation

higher (lower) than the equilibrium profile associated with the wave conditions prevailing, the sand on the beach will be transported offshore (onshore) in order to adjust the beach toward an equilibrium condition. Since the littoral drift is negligible, as noted above, for the beach being studied, and the beach is uniform laterally, it is logical to assume that essentially all of the net volume changes computed from daily profile changes are the result of onshore-offshore transport of sand.

It is also important to note that the beach observations used in this study were synchronized with the daily occurrence of lower low water. This results in a very nearly repetitive tidal sequence between successive observations as well as tide levels that differ only slightly from one observation to the next. It was assumed that this choice of sampling interval largely filters out or minimizes the effect of the tides, and that most of the beach changes measured are, therefore, attributable to changing wave conditions alone.

Finally, it should be noted that this study was limited to the exposed intertidal portion of the beach above the lowest daily tide level. The reason for this was the practical difficulty of making measurements in the surf zone. However, it has been demonstrated that the exposed portion of the beach profile above the low tide level behaves very differently from the section to seaward (Rector, 1954; King, 1959; Eubanks, 1968). It is therefore considered that the beach above the

low tide level may be studied as a separate unit.

III. DATA ANALYSIS

A. BEACH DATA

1. Computation of Sand Transport

Computation of the daily volume transport on and off the beach was based on the assumption that all sand volume changes occurring on the beach represent onshore-offshore transport of sand, as stated previously. Since no profile changes occurred above the highest reach of the waves, the rear of the beach was taken as a landward boundary across which no transport occurred. Thus, if a given rail or point on the profile is selected, the net transport of sand up or down the beach past that point from one observation to the next is given by the sum of the volume changes occurring between all of the rails landward of the point.

It was desired to examine the day-to-day volume change over the entire beachface; accordingly, a reference rail was selected at the toe of the beach at approximately the low tide level past which onshore-offshore sand transport to and from the beachface was computed. The rail lowest on the beach which had been continuously accessible at low tide over the period of the study was Rail 17; this rail was, therefore, chosen as the reference rail (Figure 4).

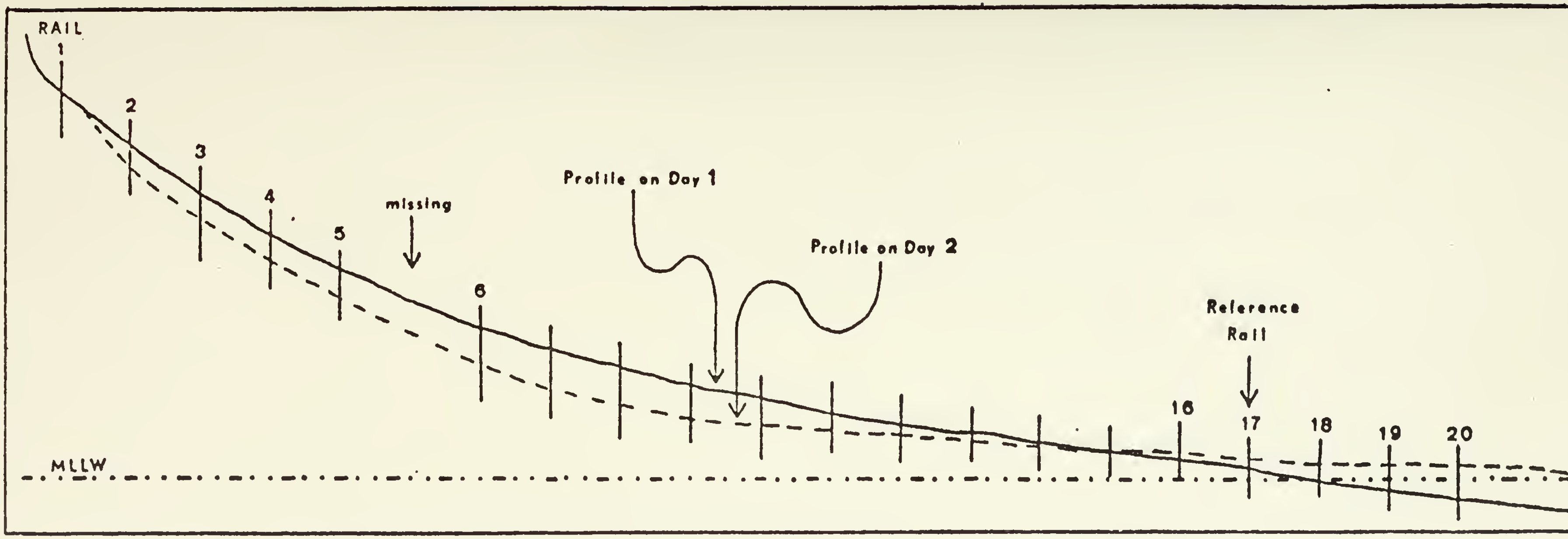
The net volume of sand transported onshore or offshore past this rail from one day to the next for a unit beach width (1 foot) was computed according to the procedure illustrated

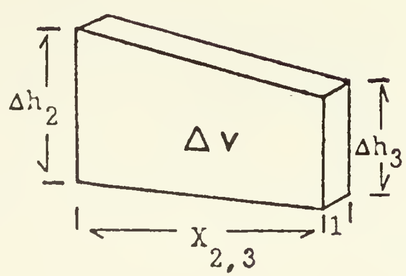
in Figure 5. First, the volume change per unit beach width between two adjacent rails from one observation to the next was approximated by the volume of a trapezoidal solid of unit width as shown in the figure. The volume changes between the successive pairs of rails were then summed from the back of the beach to the reference rail, with the resultant sum being the net volume of sand transported past the reference rail during the period. Net onshore transport past the reference rail, which represents sand gain, was taken as positive, while offshore transport representing sand loss was taken as negative.

The net daily sand transports past Rail 17 for the two-month period of the study are shown graphically in Figure 7. These transport values were also cumulated over the two-month period, and are shown in Figure 8. The cumulative sand transport represents the net accumulation on or loss of sand from the beach since the beginning of the study. The daily volume transport values past each rail on the profile calculated for the two-month period covered by this study are presented in Appendix A.

2. Computation of Initial Beach Slope

In addition to describing daily changes in the beach profile in terms of volume changes, the necessity of describing the condition of the beach before an observed change occurs is apparent from the following considerations. It has been demonstrated by studies in both laboratory and natural





$$\Delta h = (h_1 - h_2)$$

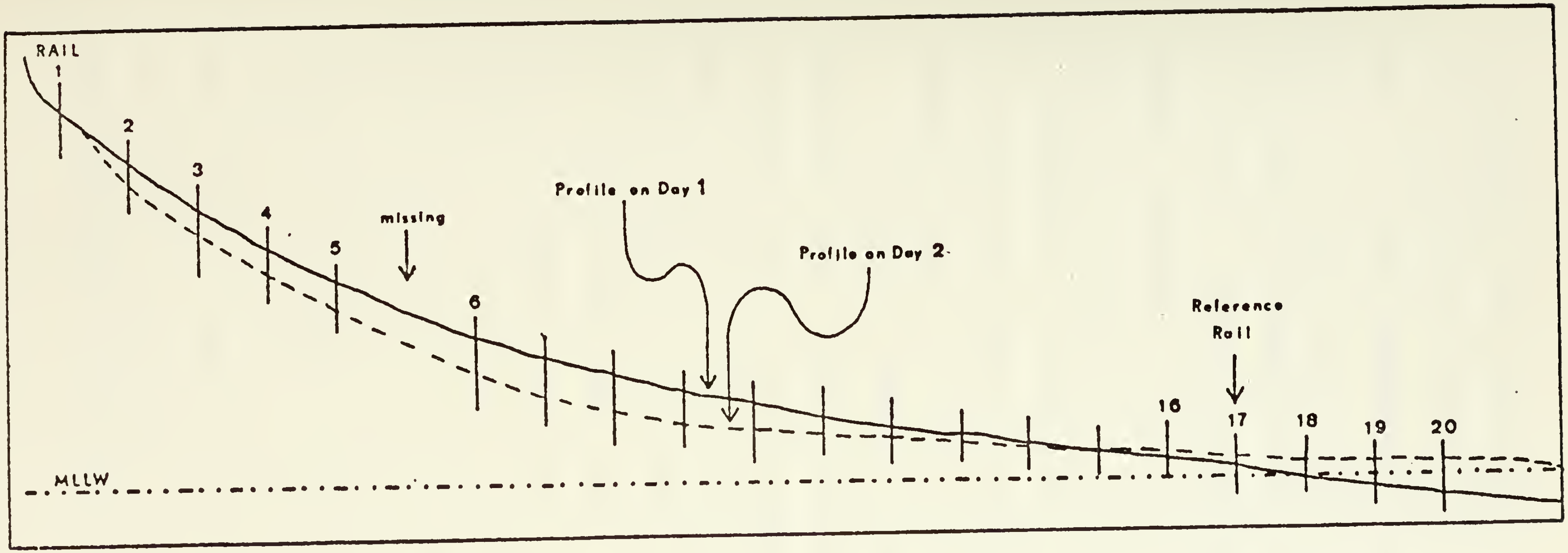
$$\Delta V = \tfrac{1}{2} (\Delta h_2 + \Delta h_3) \cdot X_{2,3}$$

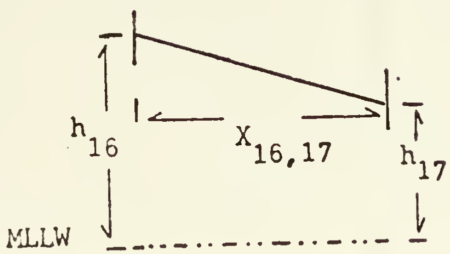
Sand transport past Rail 17 between days 1 & 2:

$$V = \sum \Delta V_{i,j}$$

where $j = i+1$.

Figure 5: CALCULATION OF SAND TRANSPORT





Beach slope between Rail 16 & Rail 17:

$$\alpha_{16,17} = (h_{16} - h_{17}) / X_{16,17}$$

Mean beach slope above Rail 17:

$$\bar{\alpha}_{17} = 1 / (17 - n) \sum \alpha_{i,j}$$

where $j = i+1$ and n is the highest rail effected by wave action during the period of time between days 1 & 2.

Figure 6: CALCULATION OF BEACH SLOPE

environments that a given set of waves will produce a unique equilibrium beach profile. It is logical to assume that if, at the beginning of a daily sampling interval, a beach is steeper (less steep) than the equilibrium profile that would be produced by the wave conditions existing during the interval, the sand on the beach will be transported offshore (onshore) in order to adjust the beach toward the equilibrium condition. Accordingly, the initial condition of the beach at the beginning of a daily sampling interval is an essential factor in determining the volume of sand transported onto or off the beach during the interval.

Since the volume-transport parameter chatacterizing the beach change during the interval was integrated across the beach face, it is reasonable to adopt an integrated measure for the initial beach condition. The initial beach condition parameter selected of several that were considered was "initial mean beach slope". This quantity was calculated using the method illustrated in Figure 6. First, the difference in sand elevation between adjacent pairs of rails was divided by the distance between them. These slopes were then averaged across the beach from Rail 17 to the highest point reached by wave action during the interval. The upper extent of wave action on the beach was taken to be that point above which no change occurred in the beach profile from one day's profile measurements to the next. Values of the initial mean beach slope above Rail 17 are presented in Appendix C.

B. WAVE AND TIDE DATA

The wave data, presented as a time series in Figure 7, were obtained by analysis of strip-chart records which covered most of the period of the study. These records were analyzed manually for wave height at the recorder depth and wave period by Professor W. C. Thompson of the Naval Postgraduate School. Significant wave heights at the recorder were determined from the slow-trace records using the method described by Harlett (1967). Wave periods were determined from 5-minute fast-trace records made every two hours using the wave-group method (Thompson, 1972).

The basic wave parameters used in this study were deep-water unrefracted wave height, H_o', and dominant wave period, T. H_o' was used to provide a standard wave height measure. Since the waves were long, low swell with steepnesses characteristically well below 1:100 during nearly all of the period covered by the study, all calculations and corrections made to obtain the wave parameters used were performed utilizing Airy or linear wave theory. Two additional wave parameters used in this study, referred to as derived parameters because they each contain as the only variables the basic parameters H_o' and T, are introduced later.

To obtain H_o', the significant height at the sensor depth was first converted to surface wave height by correcting for hydrodynamic damping. This was done by applying the pressure response factor obtained from Wiegel's (1964) tables.

The surface wave height at the recorder site was then corrected for shoaling to obtain H_o', also utilizing Wiegel's tables. Both the hydrodynamic damping correction and the shoaling correction are functions of the relative depth d/L_o, where d is the depth at the sensor site and L_o is the deep-water wave length. For these calculations a recorder depth of 30 feet was used and L_o was determined from the linear wave theory relationship

$$L_o = (g/2\pi)T^2,$$

where T is the dominant period in seconds. It can be seen that the calculation of H_o' is dependent upon having a unique value for the period.

The wave period used in this study is the dominant period present. This was obtained by plotting as a time series the period, T_g, of wave groups and periodic sequences present in the analog records. The distribution of the values of T_g on the graph, which numbered about 60 values per day on the average, allowed identification of individual wave trains that arrived on the beach during the period of the observations. The dominant period, T, was then obtained from a smooth curve fitted to the values of T_g representing each wave train. The latter curves are shown in Figure 7.

Among the wave-period information shown in the figure, individual swell trains, each generated in a given storm, can be readily identified by their characteristic period decrease with time (e.g., 20 - 22 February). The figure

shows that approximately 15 swell trains arrived on the beach during the period for which data are available. Where one swell train dies out and is replaced by a new swell train, the wave period normally shows a rapid transition toward the longer period of the new train (e.g., 15 - 16 March). Wind waves, reduced in height by the sheltering effect of the peninsula, were detected by the wave sensor on only five occasions and can be identified in the figure by initially rising and then falling periods (e.g., 1 - 5 March). When more than one wave train was present simultaneously, the period was taken to be that period associated with the train possessing greater energy (note the swell train followed by the wind wave train on 1 - 5 March). There is some subjectivity in the identification of individual wave trains from the raw wave data, but most were clear cut and left no doubt as to their occurrence.

The intervals labeled "no data" in Figure 7 were due to an unsatisfactory programming interval for the fast trace needed to obtain a suitable distribution of group period, T_g. Without the group period, neither the dominant period nor H_o' could be calculated.

The waves during the two months were mainly long, low swell, with significant wind waves being present on only five occasions, February 13 - 15, March 2 - 4, 24, 26 - 27, and 28 - 29. Values of H_o' ranged from 0.13 feet to 5.96 feet, with heights being one foot or less approximately 50% of the

time. Most wave heights greater than one foot were associated with wind-wave events. Periods ranged from 4 to 20 seconds, with swell events being characterized by periods in the 8 to 20 second range and wind-wave events by periods in the 4 to 12 second range. The interval of generally very low waves occurring between the 16th and 23rd of March exhibited much scattering as indicated by the broad background of group periods obtained from the analysis.

The tides, with respect to MLLW, for the period covered by the study were taken from the marigrams recorded on the standard recording tide gauge maintained by the Naval Postgraduate School on Monterey Municipal Wharf No. 2 in Monterey Harbor (Figure 2), and are shown plotted in Figure 7. The range of the tide and the times of springs and neaps are readily apparent.

For ease of reference, dots were placed on the wave and tide curves in Figure 7 at the times corresponding to beach observation times.

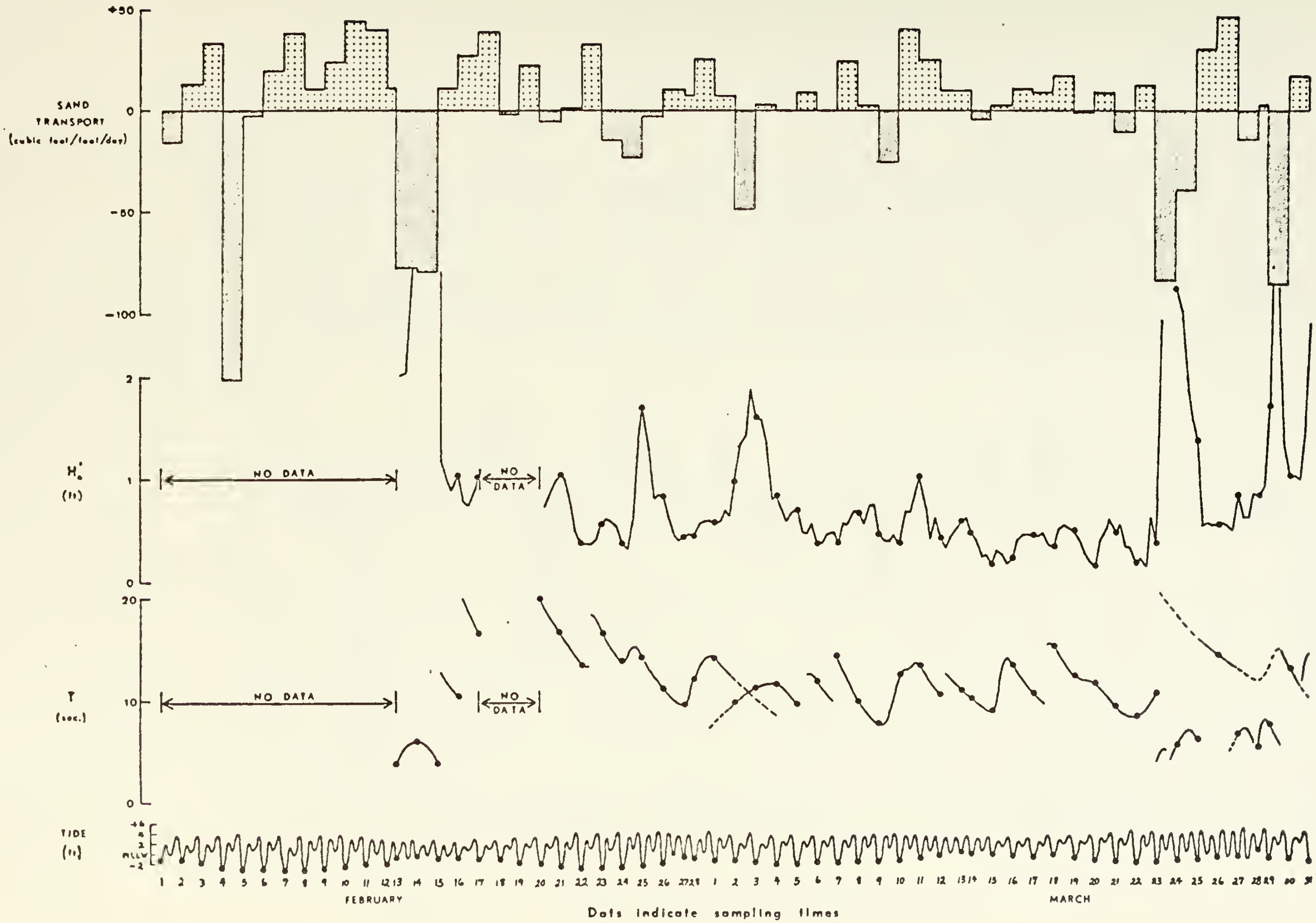


Figure 7: DAILY SAND TRANSPORTS AND WAVE AND TIDE DATA

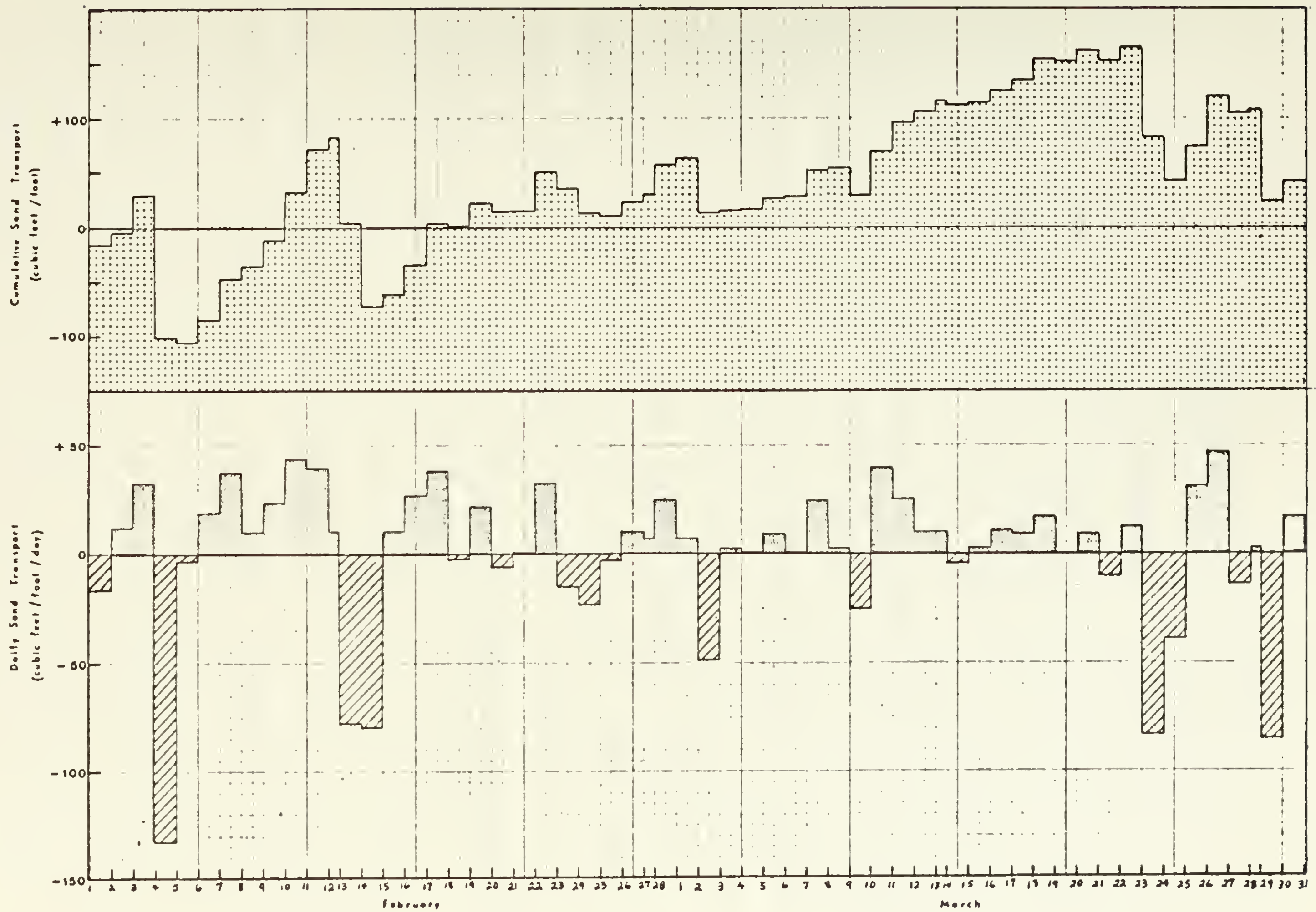


Figure 8: CUMULATIVE SAND TRANSPORTS

IV. RESULTS AND INTERPRETATION

A. OBSERVED ONSHORE-OFFSHORE SAND TRANSPORTS

The onshore-offshore sand transports occurring on the selected beach over the two-month period of the study are presented in histogram form in Figure 7 and cumulated in Figure 8. The daily transports and cumulative transports are plotted against a time scale composed of intervals corresponding to the times between successive beach profile observations. Most intervals on the time scale are equivalent to one lunar tidal cycle or 24.8 hours; however, when two successive daylight occurrences of low water are only 12.4 hours apart the graphed interval is indicated as only half as long. The sampling interval between beach-profile observations is hereafter referred to as a "period".

It has been stated previously that Rail 17 on the profile was used as the reference point for onshore-offshore volume transport computations, and that transports past Rail 17 give a measure of the net day-to-day volume change over essentially the entire beach face. Figure 7 indicates, for example, that 16.7 cubic feet of sand per foot of beach width were moved offshore past Rail 17 during the 24.8 hour interval between the profile measurements on days 1 and 2.

Perhaps the most striking feature of Figure 7 is that offshore transport, indicating erosion of the beach face, was normally limited to isolated events of large magnitude lasting

only a day or two, in which as much as 156.3 cubic feet of sand per foot of beach width per event was carried past the reference rail. The offshore transport during a 24.8 hour period had a maximum value of 132.5 cubic feet/foot/period and averaged about 35 cubic feet/foot/period.

Onshore transport prevailed during 69% of the period covered by the study, and normally occurred daily over a series of successive days. The magnitudes of onshore daily sand transport were, however, much lower than those of offshore transport, with the maximum onshore transport of sand past Rail 17 being 47.0 cubic feet/foot/period. Onshore transports averaged only about 15 cubic feet/foot/period, with transports during roughly half the accretion periods being less than 10 cubic feet/foot/period.

It may be seen in Figure 7 that transport may change abruptly from one day to the next in both magnitude and direction. Examination of the associated wave data indicates that these changes are sensitive to changes in the waves incident upon the beach. It is apparent that large offshore transports correspond roughly to times of increased wave height although no correlation was found in the magnitudes of these.

The graph of cumulative volume transport past Rail 17 from day-to-day, presented in Figure 8, shows the net or cumulative volume change in the beach occurring over the two-month period covered by the study. The first profile measurement

of the series was used as the reference point in time for cumulating the transports; however, the volume changes over any period of time desired can be obtained from the figure.

In Figure 8 it may be seen that the beach tended to build throughout the two-month period. This trend can be considered to represent a two-month segment of the seasonal cycle occurring on this beach, the segment closely following the extreme winter condition that has been observed to occur in January on California beaches (Shepard, 1950; Johnson, 1971).

B. RELATION BETWEEN VOLUME TRANSPORT AND INCIDENT WAVES

In view of the relatively simple nature of the beach being studied and the association that may be observed in Figure 7 between waves and sand transport, it was concluded that it should be possible quantitatively to relate the daily sand transports to the incident waves. In addition to the basic wave parameters H_o' and T, it was decided to additionally characterize the waves by their initial steepness, γ_o', and power, P.

The selection of steepness as a wave parameter seemed logical because of its demonstrated relationship to numerous wave characteristics such as mass transport, breaker height, breaker type, and wave runup.

The initial wave steepness is given by $\gamma_o' = H_o'/L_o$. For purposes of correlation, it was found that the mean steepness, $\overline{\gamma}_o'$, occurring over the 24.8 - hour interval between beach

observations gave the best measure of the wave steepness for use in explaining the volume changes observed on the beach over that interval. The mean steepness over the interval was computed by averaging the steepness at the final observation time with the steepness values calculated every 6.2 hours during the interval preceeding the observation, i.e.,

$$\bar{\gamma}_o' = 1/4 \left[\gamma_{o_i}' + \gamma_{o_{i-6.2}}' + \gamma_{o_{i-12.4}}' + \gamma_{o_{i-18.6}}' \right],$$

where i represents the beach profile observation time at the end of a period.

Wave power was selected as a parameter since it is indicative of the amount of energy available over a period of time to perform the work of moving sand up and down the beach. Wave power may be determined from the Airy relationship

$$P = (\rho g/16)(g/2\pi)(H_o')^2 T \quad \text{(ft-lbf/sec-ft)}$$

where g is the acceleration of gravity, ρ is the average density of seawater (2.0 slug/ft^3), and T is the dominant wave period. For purposes of correlation, mean wave power over the 24.8 hour interval between beach observations was assumed to give the best measure of power. This quantity was calculated in a manner similar to γ_o'.

A tabulation of all wave and beach parameters used in this study is given in Table 1.

Table 1

WAVE AND BEACH PARAMETERS

Wave Parameters

H'_o	Deep water unrefracted wave height.	$H'_o = K_d.K_s.H_g$ K_d = Damping coefficient K_s = Shoaling Coefficient H_g = Wave height at sensor depth
T	Dominant wave period.	Extracted manually from wave records.
$\overline{\gamma}'_o$	Mean initial wave steepness.	From one profile observation to the next.
$\overline{P}'$	Mean wave power.	From one profile observation to the next.

Beach Parameters

V	Daily sand transport.	From one profile observation to the next. + = onshore - = offshore
$\overline{\alpha}_i$	Initial mean beach slope above Rail 17.	At time of profile observation at the beginning of a period.

1. Synoptic Wave Events

The first step taken toward establishing a relationship between beach changes and the incident waves was to construct a graph of synoptic wave events. The ordinates of the graph are H_o' and T. Two families of curves of γ_o' and P', both of which are functions solely of H_o' and T, are shown on the graph. These curves do not extend into the area left of the curve labeled "limiting steepness", which, for practical purposes, is taken to be $H_o'/L_o = 0.10$.

A synoptic wave event is defined as the series of waves arriving on the beach over a period of time from a single generating source, and may be a swell train from a distant storm or wind waves of local origin. By way of illustration, Figures 9A through 9D present selected wave events occurring on the indicated dates. The H_o'-T combinations occurring at beach observation times are indicated by a circled dot and labeled with the date; the H_o'-T combinations at 6.2-hour intervals in between are indicated by a dot only. These are connected by a directed, continuous time curve from which can be read the height-period combination for the wave train at any moment during its life.

On such a graph, swell and wind wave events each have a distinctive form. A swell event, such as the event of February 20 - 22 in Figure 9A, normally begins on the right of the graph with the earliest wave arrivals being of long period and low height. As time progresses the period decreases, and the height increases, with the resulting

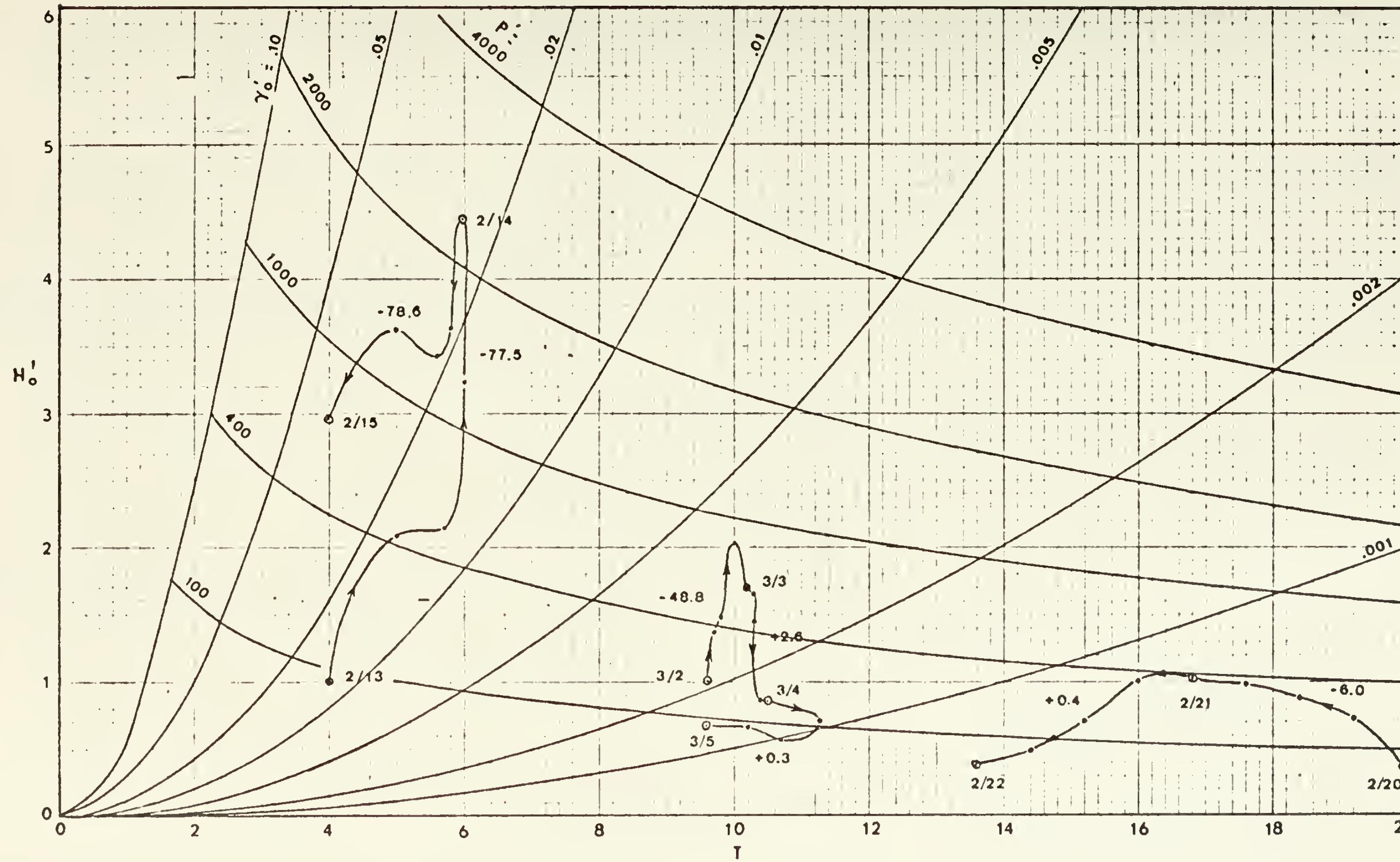
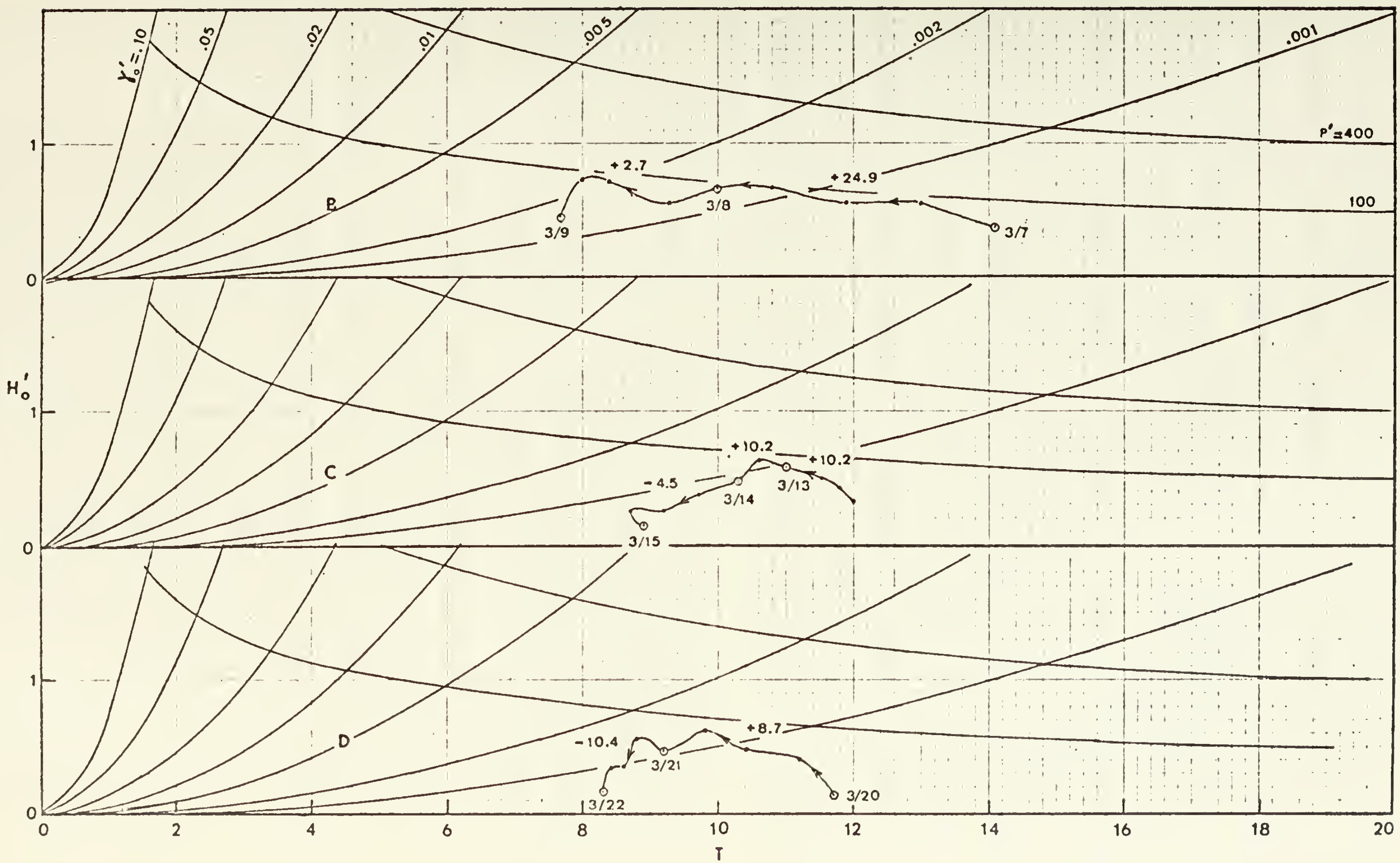


Figure 9A: SYNOPTIC WAVE EVENTS



Figures 9B-9D: SYNOPTIC WAVE EVENTS

height-period "vector" being directed upward and to the left, crossing lines of increasing power and steepness. After the peak height, or power, for the swell train is reached, the vector descends, crossing lines of decreasing power, with steepness either being roughly constant or decreasing. A wind-wave train exhibits a very different character, and is illustrated in Figure 9A by the wave event of March 2 - 4. The vector representative of wind waves begins in the lower left-hand corner of the graph with small, steep waves. As the wave height builds, the steepness remains large until the peak power is reached; after which the height-period vector descends in a manner similar to that of the waning portion of a swell event.

The sand-volume transports occurring between successive beach observations are shown numerically on the appropriate portions of the H_o'-T curves in cubic feet/foot/period. When the transports are associated with the graphed intervals between beach observations in Figures 9A through 9D a pattern emerges. It can be seen that whenever there is an increase in steepness and power between beach observations, there is normally a corresponding offshore (negative) transport. This is true for both wind wave and swell events. After the peak wave height in an event is passed and the wave heights begin to decrease, the beach normally begins to accrete. It may be noted in Figure 9A, however, that for the wave event of February 13 - 15, offshore transport continued even after the peak height had passed. This lag in response of the

beach to changing wave conditions would seem to indicate that for some hours after the wave heights had begun to decrease, the beach was still at a higher elevation, or was steeper, than the equilibrium condition for the wave conditions prevailing over that period. This observation is consistent with the argument that on a beach which is initially at an elevation higher than, or has a slope greater than, that of the equilibrium profile for the existing wave conditions, transport will be offshore. It is thus apparent that the initial condition of the beach must be taken into account in any attempt to correlate daily sand transports with the existing wave conditions.

2. Wave-Beach Correlation

The relationship between beach changes and the incident wave conditions was examined using an empirical graphical approach. Three-factor graphs were constructed, with transport values being plotted for various logical combinations of the wave and beach parameters listed in Table 1. From the basic considerations given in Section II and from insight gained from the examination of Figures 7 and 9A through 9D, it was determined, following some experimentation, that the components of a satisfactory relationship between incident wave conditions and beach response include:

(1) the volume transport, V, occurring over the period between two successive beach observations,

(2) the mean beach slope, $\overline{\alpha}_i$, at the beginning of the

period, and

(3) the mean wave steepness, $\overline{\gamma}_o'$, over the period between the two successive beach observations.

The results of this correlation are presented in Figure 10. This figure contains all of the data for the two-month study with the exception of the data for the period of extremely low waves from March 11 to 22, during which scatter of the data was extreme.

It is apparent from examination of this graph that a reasonably good, first-order relationship exists between these parameters. For each given average wave steepness, for example, there is apparently an equilibrium average beach slope, as indicated by the zero transport curve labeled "equilibrium condition". As the waves become steeper for a given initial beach slope, sand is transported off the beach, the beach is eroded, and that portion of the beach affected by the waves comes to have a gentler average slope. The converse is also true, but the relationship seems less well defined for onshore transports than for offshore transports. This agrees with the qualitative observations of Shepard (1963) and others that waves of low steepness are constructive and waves of high steepness are destructive, and with the statement of Wiegel (1964) that "normal" wave conditions tend to move offshore sand toward a beach, while "storm" conditions cause erosion of the beach.

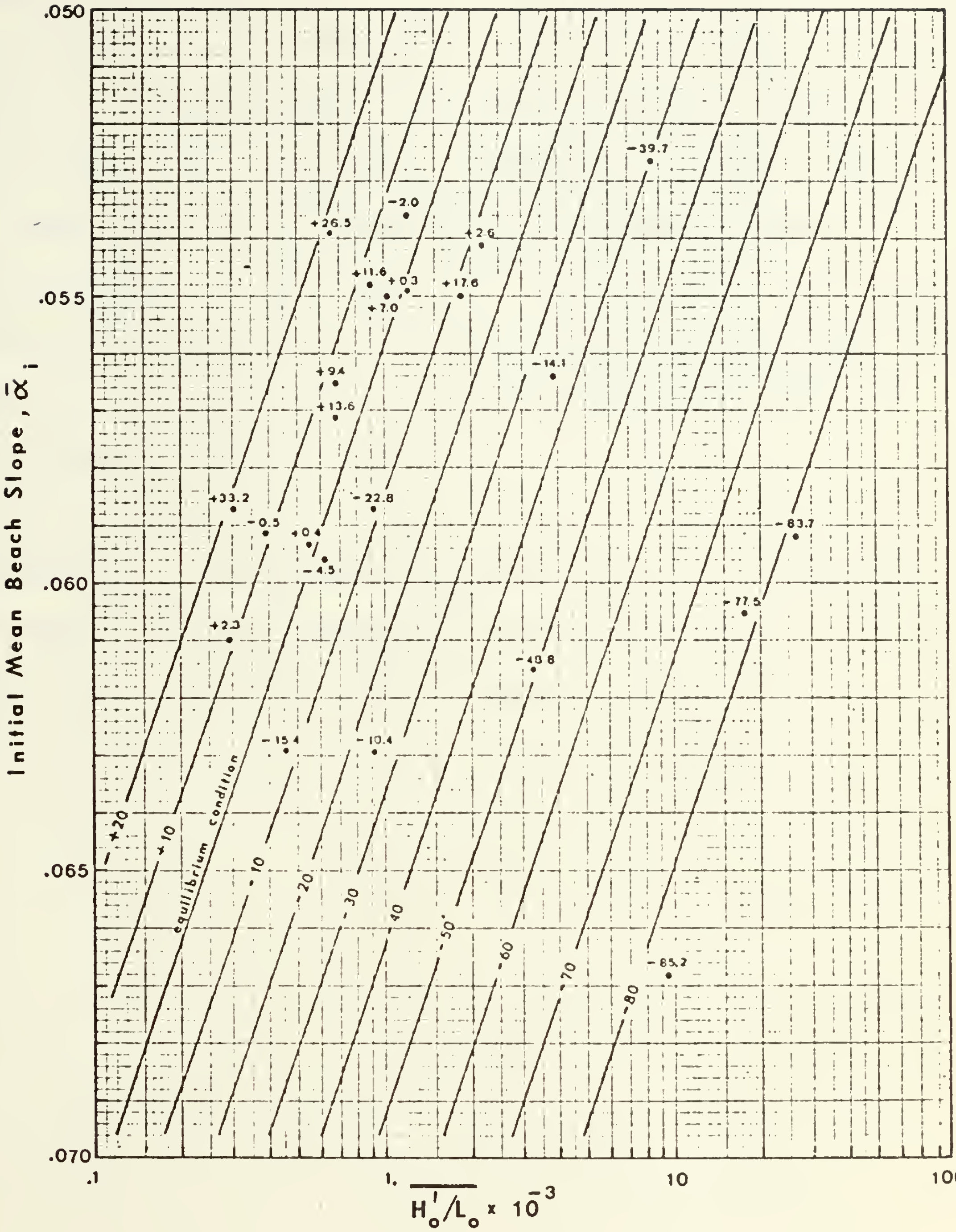


Figure 10: DAILY SAND TRANSPORT AS A FUNCTION OF WAVE STEEPNESS AND INITIAL BEACH SLOPE

C. THE EFFECT OF WAVE POWER AND THE TIDES

Correlations were attempted utilizing wave power as a parameter. No relationship was observed, however, and it was concluded that wave power is probably, at most, of only minor importance in the determination of sand transport values. Similarly, even during the long period of low waves in mid-March when some tidal effects appear to have occurred (Figure 7), no quantitative relation between the tides and sand transports could be developed.

In the final analysis, it is clear from the nature of the variation of the volume transports from day to day that beach changes reflect primarily variably changing wave conditions rather than the regular changes of the tides.

V. CONCLUSIONS

The conclusions reached in this investigation of the daily volume changes over a two-month period in the exposed profile of Del Monte Beach, California, are as follows:

(1) Offshore transport of sand from the beachface occurred as isolated events of usually large magnitude lasting one to two days. Onshore transport occurred over longer intervals of time of up to seven consecutive days and was of relatively small daily magnitude. Onshore transport prevailed during 69% of the period covered by the study.

(2) Offshore transport past Rail 17, located at the foot of the beachface, averaged approximately 35 cubic feet of sand/foot of beach width/lunar day (24.8 hours), and had a maximum value of 132.5 cubic feet/foot/day. Onshore transport, on the other hand, averaged only about 15 cubic feet/foot/day, with the maximum being 47.0 cubic feet/foot/day. The maximum volume of sand carried off the beach during an offshore transport event was 156.3 cubic feet/foot of beach width, while that returned during an onshore transport event was 189.2 cubic feet/foot.

(3) The large offshore transports were normally associated with wind waves or swell of larger steepness and wave heights (H_o') of 1 to 5 feet, while the smaller

onshore transports were associated with swell of very small steepness and wave heights of less than a foot.

(4) Numerous correlation attempts utilizing both wave steepness and power as parameters indicate that wave steepness greatly influences onshore-offshore sand volume transport, while wave power is of generally secondary importance.

(5) The onshore-offshore transport of sand during a lunar day (chosen to minimize the effect of the tides) depends to a first approximation upon the mean beach slope at the beginning of the period and the average wave steepness during the period (Figure 10). If the initial mean beach slope is greater than the slope of the equilibrium profile associated with the existing wave steepness, or if the profile is initially at equilibrium and the wave steepness increases, sand will be moved offshore (the beach will erode) until the equilibrium profile for the new wave conditions is reached. Conversely, if the initial mean beach slope is less than that for the equilibrium profile, or if the wave steepness has decreased, sand will be transported onshore until the equilibrium is reached. The closer to equilibrium the beach is, the smaller the transports are.

The results of this study probably generally characterize relatively sheltered sand beaches along coasts where the open-ocean wave regime is generally similar.

LIST OF REFERENCES

1. Eubanks, G. E., 1968. A field study of tide-induced sand movement on Del Monte Beach, California. Naval Postgraduate School, Monterey, California, M.S. Thesis, 52 pp.

2. Harlett, J. C., 1967. Daily changes in beach profile and sand texture on Del Monte Beach, California. Naval Postgraduate School, Monterey, California, M.S. Thesis, 84 pp.

3. Harrison, W., et al., 1968. A time series from the beach environment. Environmental Science Services Administration, Atlantic Oceanographic Laboratories Technical Memorandum No. 1, 28 pp.

4. Haydock, D. G., 1969. Alteration of a beach profile during a tidal cycle. Naval Postgraduate School, Research Paper in Oceanography, 43 pp.

5. Monterey Bay, California. House Document No. 219, 86th Congress, 1st Session, Appendix V: Shoreline Changes, 27 August 1959.

6. Ingle, J. C., 1966. The movement of beach sand. Elsevier, 221 pp.

7. Inman, D. L., and J. Filloux, 1960. Beach cycles related to tide and local wind wave regime. Journal of Geology, V. 68, No. 2, pp. 225-231.

8. Ippen, A. T., and P. S. Eagleson, eds., 1966. Estuary and coastline hydrodynamics. McGraw-Hill, 744 pp.

9. Johnson, J.W., 1971. The significance of seasonal beach changes in tidal boundaries. Journal of the American Shore and Beach Preservation Association, V 39, No. 1, pp. 26-31.

10. King, C. A. M., 1959. Beaches and coasts. Edward Arnold, Ltd., London, 403 pp.

11. Nayak, I. V., 1970. Equilibrium profiles of model beaches. University of California, Hydraulic Engineering Laboratory, Technical Report HEL-2-25, 117 pp.

12. Rector, R. L., 1954. Laboratory study of equilibrium profiles of beaches. Corps of Engineers, Beach Erosion Board, Technical Memorandum No. 41, 38 pp.

13. Rohrbough, J. D., J. E. Koehr, and W. C. Thompson, 1954. Quasi-weekly and daily profile changes on a distinctive sand beach. American Society of Civil Engineers Proceedings of Ninth Conference on Coastal Engineering, Chapter 16, pp. 249-258.

14. Shepard, F. P., and E. C. LaFond, 1940. Sand movement along the Scripps Institution pier. American Journal of Science, V. 238, pp. 272-285.

15. Shepard, F. P., 1950. Beach cycles in Southern California. Corps of Engineers, Beach Erosion Board, Technical Memorandom No. 20, 26 pp.

16. Shepard, F. P., 1963. Submarine geology. Harper and Row, Second Edition, 557 pp.

17. Strahler, A. N., 1964. Tidal cycle of changes in an equilibrium beach, Sandy Hook, N. J. Columbia University, Department of Geology, Technical Report No. 7, 51 pp.

18. Thompson, W. C., and J. C. Harlett, 1969. The effect of waves on the profile of a natural beach. American Society of Civil Engineers, Proceedings of Eleventh Conference on Coastal Engineering, Chapter 23, pp. 352-372.

19. Thompson, W. C., 1972. Wave frequency by the wave-group method. American Society of Civil Engineers, Proceedings of Thirteenth Conference on Coastal Engineering, Abstract.

20. Watts, G. M., 1954. Laboratory study of effect on varying wave periods on beach profiles. Corps of Engineers, Beach Erosion Board, Technical Memorandum No. 53, 19 pp.

21. Watts, G. M., and R. F. Dearduff, 1954. Laboratory study of effect of tidal action on wave-formed beach profiles. Corps of Engineers, Beach Erosion Board, Technical Memorandum No. 52, 21 pp.

22. Wiegel, R. L., 1964. Oceanographical engineering. Prentice-Hall, 532 pp.

APPENDIX A

DAILY SAND VOLUME TRANSPORTS

Transports are in cubic feet of sand/foot of beach width/period carried past a given rail on the profile, between observations on the dates indicated. A period is the interval of time between two successive beach profile observations.

RAIL

DATE	2	3	4	5	6	7	8	9	10	11
2/1-2	0.0	0.0	0.4	-0.4	-4.8	-6.8	-8.7	-10.9	-13.3	-15.3
2-3	0.0	0.1	0.4	1.0	0.8	-0.1	-0.6	-0.5	0.4	1.8
3-4	0.0	0.0	0.0	0.2	2.4	4.4	6.4	9.0	11.5	13.8
4-5	0.0	1.5	1.7	-3.6	-22.6	-35.4	-47.2	-58.9	-69.5	-78.9
5-6	0.0	0.6	2.5	4.8	9.9	12.4	14.2	14.9	14.5	13.5
6-7	0.0	0.0	-0.0	-1.9	-2.0	1.5	4.9	7.9	10.0	11.4
7-8	0.0	0.0	-0.0	3.9	15.2	18.8	21.4	22.2	23.0	25.1
8-9	0.0	0.1	2.0	4.4	4.8	3.0	1.3	1.3	1.8	1.5
9-10	0.0	-0.1	-0.1	0.0	3.2	3.2	3.9	8.7	13.5	18.1
10-11	0.0	0.0	0.0	0.0	1.0	7.7	16.4	22.5	27.6	31.2
11-12	0.0	0.0	0.0	0.0	0.6	2.1	4.5	8.1	12.6	17.2
12-13	0.0	0.0	0.0	0.0	0.0	0.1	0.7	3.9	8.8	12.1
13.14	0.0	0.0	0.1	1.4	6.1	6.2	0.9	-10.7	-25.1	-37.7
14-15	0.0	0.0	0.1	0.1	-1.5	-4.3	-7.6	-10.7	-13.9	-17.2
15-16	0.0	0.0	0.0	0.0	-1.7	-2.1	-1.4	-0.8	-0.8	-1.0
16-17	0.0	0.0	0.0	0.0	4.7	8.4	9.8	9.6	8.2	6.4
17-18	0.0	0.0	0.0	0.1	1.4	1.7	1.7	3.1	5.8	9.2
18-19	0.0	0.0	0.1	0.5	0.5	0.3	1.3	3.3	5.3	6.9
19-20	0.0	0.0	0.0	0.0	3.0	6.0	7.9	9.0	9.7	10.6
20-21	0.0	-0.1	0.3	1.3	-0.7	-3.8	-6.2	-7.9	-8.6	-8.7
21-22	0.0	-0.1	0.1	1.0	0.4	-1.0	-1.6	-1.9	-2.2	-2.3
22-23	0.0	0.0	0.0	0.2	-2.1	-4.1	-3.9	-1.4	2.7	7.7
23-24	0.0	0.2	1.1	-3.1	-15.3	-17.1	-18.1	-18.9	-19.1	-18.9
24-25	0.0	-0.1	-4.7	-8.4	-6.5	-5.9	-5.7	-5.9	-7.2	-9.4
25-26	0.0	0.0	1.0	2.7	5.7	6.8	7.1	6.9	6.1	5.1

	RAIL								
DATE	12	13	14	15	16	17	18	19	20
2/1-2	-16.8	-17.9	-18.5	-18.3	-17.7	-16.7	-15.5	-14.1	-13.2
2-3	5.1	8.5	10.0	11.3	12.2	12.8	13.3	13.9	14.3
3-4	14.8	16.2	19.5	23.5	27.9	33.6	39.8	46.4	52.2
4-5	-88.2	-97.3	-106.0	-114.8	-123.1	-132.5	-142.4	-153.5	-163.2
5-6	12.2	8.6	4.8	2.6	0.2	-2.4	-4.7	-5.9	-7.0
6-7	12.0	14.1	16.2	16.7	17.8	19.8	22.5	25.7	28.5
7-8	27.3	29.6	31.7	33.8	35.9	38.0	39.5	40.5	41.3
8-9	2.0	3.0	4.9	7.2	9.2	11.0	12.2	13.4	14.7
9-10	20.6	22.3	24.3	25.1	25.2	24.7	24.0	23.0	21.3
10-11	35.6	39-5	41.3	42.6	43.4	44.2	44.6	44.4	44.2
11-12	22.1	27.1	32.1	36.3	39.0	40.0	39.5	38.5	37.7
12-13	13.8	14.7	14.4	13.2	12.4	11.4	10.1	9.0	8.6
13-14	-48.7	-58.2	-64.6	-68.1	-73.1	-77.5	-80.1	-82.5	*******
14-15	-21.6	-29.1	-41.7	-57.1	-69.4	-78.8	*******	*******	*******
15-16	-0.9	0.6	3.3	6.0	8.4	10.1	*******	*******	*******
16-17	5.1	4.8	6.8	12.3	19.6	27.6	33.4	*******	*******
17-18	13.2	18.8	25.1	31.2	35.6	38.3	40.7	42.5	*******
18-19	6.3	4.9	4.4	2.8	0.5	-2.2	-4.7	-6.2	-6.7
19-20	13.3	15.6	16.1	17.2	19.0	22.0	26.0	31.2	36.5
20-21	-8.5	-8.0	-7.3	-6.4	-6.0	-6.0	-6.4	-7.0	-7.3
21-22	-2.0	-1.6	-0.8	-0.0	-0.5	0.4	-0.4	-2.5	-5.4
22-23	13.0	18.3	23.1	27.2	30.4	33.2	35.5	37.8	39.5
23-24	-18.2	-17.4	-16.9	-16.5	-16.1	-15.4	-14.5	-14.0	-13.8
24-25	-12.2	-15.3	-17.9	-19.8	-21.0	-22.8	-25.8	-29.3	-33.3
25-26	4.2	3.5	2.5	0.8	-0.9	-2.0	-1.7	-0.2	1.9

DATE	RAIL 2	3	4	5	6	7	8	9	10	11
26-27	0.0	0.0	0.0	0.0	0.0	0.9	3.2	6.6	10.4	13.0
27-28	0.0	0.0	0.0	0.0	0.2	1.8	5.8	9.6	10.5	10.0
2/28-3/1	0.0	0.0	0.0	0.0	2.2	4.0	4.2	4.4	6.5	10.0
1-2	0.0	0.0	0.0	0.0	1.6	4.1	7.5	10.7	12.4	13.1
2-3	0.0	0.0	0.5	1.2	-3.9	-12.4	-23.6	-35.5	-44.0	-49.8
3-4	0.0	0.0	0.0	0.0	3.4	7.2	10.3	12.7	13.4	12.5
4-5	0.0	0.0	0.0	0.0	0.9	2.0	3.9	5.9	7.4	8.2
5-6	0.0	0.0	0.0	0.0	0.5	1.7	3.4	4.7	5.5	6.3
6-7	0.0	0.0	0.0	0.0	0.2	1.5	4.1	6.6	8.0	8.7
7-8	0.0	0.0	0.0	0.0	1.3	3.1	4.8	5.9	7.0	8.8
8-9	0.0	0.0	0.0	0.0	0.0	0.4	1.8	3.3	3.1	2.3
9-10	0.0	0.0	0.0	0.0	-1.7	-4.1	-9.6	-19.1	-25.3	-26.0
10-11	0.0	0.0	0.0	0.0	3.3	6.3	10.5	19.7	28.3	31.7
11-12	0.0	0.0	0.0	0.0	0.0	0.2	1.8	5.6	10.2	14.2
12-13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	4.7	7.8
13-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	2.5	5.2
14-15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	2.6
15-16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.9	4.0
16-17	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	1.2	4.1
17-18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.5
18-19	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.7	0.4	-1.7
19-20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	-0.3	1.0
20-21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.1	2.5
21-22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.2

DATE	RAIL 12	13	14	15	16	17	18	19	20
26-27	13.6	12.5	11.4	11.0	11.1	11.6	12.2	12.5	12.7
27-28	9.3	8.7	8.2	7.9	7.9	8.4	9.1	9.7	9.8
2/28-3/1	14.5	19.6	23.6	26.1	26.9	26.5	25.5	23.9	22.7
1-2	13.0	12.0	10.6	9.2	8.1	7.0	5.9	4.9	4.0
2-3	-53.6	-55.5	-55.5	-53.9	-51.4	-48.8	-46.3	-43.3	-40.0
3-4	10.9	9.3	7.5	5.5	3.7	2.6	2.3	2.3	2.6
4-5	8.1	7.2	5.7	3.8	2.0	0.3	-0.9	-1.8	-2.3
5-6	7.4	8.0	8.2	8.7	9.1	9.4	9.4	9.8	10.5
6-7	8.5	7.6	6.1	3.5	1.2	0.4	0.7	1.3	2.1
7-8	11.3	14.4	17.6	21.0	23.7	24.9	25.3	25.5	25.5
8-9	1.4	1.1	1.4	2.0	2.5	2.7	2.4	1.3	-0.3
9-10	-25.2	-25.5	-26.2	-26.8	-26.8	-26.3	-25.3	-23.7	-22.1
10-11	33.3	35.5	37.9	39.8	40.6	40.1	*******	*******	*******
11-12	17.6	20.4	22.5	24.1	25.5	26.7	*******	*******	*******
12-13	10.0	11.2	11.4	11.1	10.8	10.2	9.3	*******	*******
13-14	6.8	7.3	7.8	8.5	9.4	10.6	11.8	*******	*******
14-15	4.7	4.1	2.6	0.4	-2.2	-4.5	-5.7	*******	*******
15-16	5.9	8.7	9.7	8.5	5.7	2.3	0.9	*******	*******
16-17	7.8	10.2	11.9	12.8	12.8	11.7	10.0	*******	*******
17-18	2.8	4.5	6.0	7.8	9.3	9.5	9.8	11.1	*******
18-19	-3.4	-2.4	0.7	5.3	10.7	17.8	22.7	24.0	*******
19-20	4.8	7.5	6.1	3.1	0.7	-0.5	-0.2	0.1	0.3
20-21	1.9	0.8	1.9	4.2	6.9	8.7	8.9	9.1	9.6
21-22	0.7	-1.3	-3.3	-5.7	-8.3	-10.4	-10.6	-9.8	-8.8

DATE	RAIL 2	3	4	5	6	7	8	9	10	11
3/22-23	0.0	0.0	0.0	0.0	0.0	0.0	0.5	2.5	4.1	2.6
23-24	0.0	0.0	0.4	1.4	1.0	-3.3	-11.0	-23.7	-41.2	-58.5
24-25	0.0	0.0	0.0	0.3	5.0	8.1	7.4	4.4	1.1	-3.2
25-26	0.0	0.0	0.0	0.0	-1.9	-0.4	6.9	15.1	20.0	23.2
26-27	0.0	0.0	0.0	0.0	0.0	0.5	1.6	4.1	8.9	15.1
27-28	0.0	0.0	0.0	0.0	0.8	1.3	1.9	1.5	-0.2	-0.9
28-29	0.0	0.0	0.0	0.0	0.5	0.9	-0.5	-2.2	-2.6	-3.4
29-30	0.0	0.0	0.2	1.4	-4.0	-13.7	-24.5	-34.7	-43.4	-51.4
30-31	0.0	0.0	0.0	-1.0	-0.1	2.7	5.4	7.9	9.5	11.1

DATE	RAIL 12	13	14	15	16	17	18	19	20
3/22-23	2.2	4.9	7.5	9.7	11.8	13.6	14.0	13.7	13.5
23-24	-72.9	-83.3	-88.1	-88.6	-86.6	-83.7	-80.8	-78.3	-77.0
24-25	-8.7	-14.9	-21.0	-27.0	-33.1	-39.7	-46.0	-52.1	-57.0
25-26	25.6	27.5	29.3	30.8	32.1	31.7	30.6	30.1	28.2
26-27	23.3	30.9	35.5	39.7	42.9	47.0	49.7	49.5	*******
27-28	-2.3	-3.8	-4.6	-7.3	-10.6	-14.1	*******	*******	*******
28-29	-4.2	-4.2	-3.6	-2.2	-0.3	3.0	*******	*******	*******
29-30	-59.8	-67.7	-74.0	-78.9	-82.6	-85.2	-86.5	-86.9	-86.3
30-31	12.7	13.4	14.1	15.1	16.3	17.6	18.3	17.7	*******

* INDICATES RAIL WAS INACCESSABLE

APPENDIX B

WAVE AND TIDE DATA

Wave height at sensor depth, H_g, dominant wave period, T, hydrodynamic damping coefficient, K_d, shoaling coefficient, K_s, and deep water unrefracted wave height, H_o'. are tabulated every 6.2 hours with the date, time, and tide height (relative to MLLW) being given additionally for the times of beach profile observations. Wave data for February 1-13 and 18-20 are not tabulated.

DATE	OBSERVATION TIME (Time of LLW)	TIDE	H_g	T	K_d	K_s	H_o'
			0.75	5.0	2.575	1.078	2.08
			1.00	5.7	1.950	1.094	2.13
			1.60	6.0	1.841	1.095	3.23
2/14	0750	1.8	2.20	6.0	1.841	1.095	4.43
			1.75	5.8	1.900	1.095	3.64
			1.60	5.6	1.948	1.093	3.41
			1.30	5.0	2.575	1.078	3.61
2/15	0844	1.6	1.10	4.0	5.245	1.033	5.96
			1.15	12.8	1.119	0.920	1.18
			0.90	12.0	1.143	0.943	0.97
			0.75	11.2	1.168	0.967	0.85
2/16	0950	1.3	0.90	10.4	1.199	0.991	1.07
			0.95	20.0	1.048	0.761	0.76
			0.90	19.0	1.053	0.778	0.74
			0.90	17.9	1.060	0.799	0.76
2/17	1056	0.9	1.20	16.5	1.072	0.830	1.07
			0.90	19.2	1.052	0.775	0.73
			1.05	18.4	1.057	0.790	0.88
			1.14	17.6	1.062	0.805	0.97
2/21	1432	-0.9	1.15	16.8	1.069	0.823	1.01
			1.11	16.0	1.076	0.840	1.00
			0.75	15.2	1.085	0.860	0.70
			0.50	14.4	1.096	0.878	0.48
2/22	1514	-1.2	0.37	13.6	1.108	0.898	0.37
			0.37	13.8	1.105	0.894	0.37

DATE	OBSERVATION TIME (Time of LLW)	TIDE	H_g	T	K_d	K_s	H'_o
			0.43	18.4	1.057	0.790	0.36
			0.50	17.8	1.061	0.801	0.42
2/23	1556	-1.2	0.60	16.9	1.068	0.820	0.53
			0.66	16.0	1.076	0.840	0.60
			0.61	15.1	1.086	0.861	0.57
			0.53	14.2	1.098	0.884	0.51
2/24	1632	-1.1	0.37	14.0	1.102	0.888	0.36
			0.35	14.6	1.093	0.874	0.33
			0.63	14.8	1.090	0.869	0.60
			1.44	14.8	1.090	0.869	1.36
2/25	1714	-0.7	1.75	14.4	1.096	0.878	1.68
			1.24	13.1	1.118	0.912	1.26
			0.77	12.8	1.119	0.920	0.79
			0.77	11.9	1.145	0.947	0.83
2/26	1750	-0.1	0.72	11.2	1.168	0.967	0.81
			0.56	10.8	1.180	0.978	0.65
			0.41	10.4	1.199	0.991	0.49
			0.33	10.0	1.216	1.003	0.40
2/27	1832	0.6	0.33	9.7	1.230	1.012	0.41
			0.40	10.8	1.180	0.978	0.46
2/28	0720	0.5	0.40	12.0	1.143	0.943	0.43
			0.54	13.8	1.105	0.890	0.53
			0.59	13.1	1.118	0.912	0.60
			0.60	12.3	1.132	0.935	0.64
3/1	0832	0.3	0.58	14.2	1.098	0.884	0.56

DATE	OBSERVATION TIME (Time of LLW)	TIDE	H_g	T	K_d	K_s	H'_o
			0.58	13.7	1.107	0.896	0.58
			0.65	13.1	1.118	0.912	0.66
			0.62	12.2	1.136	0.937	0.66
3/2	0944	0.1	0.80	9.6	1.237	1.015	1.00
			1.10	9.7	1.230	1.012	1.37
			1.20	9.8	1.224	1.009	1.48
			1.65	10.0	1.216	1.003	2.01
3/3	1056	-0.1	1.40	10.2	1.210	0.997	1.69
			1.41	10.3	1.200	0.994	1.68
			1.20	10.3	1.200	0.994	1.43
			0.72	10.4	1.199	0.991	0.86
3/4	1208	-0.3	0.75	10.5	1.195	0.987	0.88
			0.65	11.2	1.168	0.967	0.73
			0.50	10.7	1.188	0.982	0.58
			0.55	10.2	1.210	0.997	0.66
3/5	1314	-0.5	0.55	9.6	1.237	1.015	0.69
			0.40	10.0	1.216	1.003	0.49
			0.45	12.6	1.124	0.926	0.47
			0.54	12.6	1.124	0.926	0.56
3/6	1408	-0.6	0.33	11.9	1.145	0.947	0.36
			0.34	11.4	1.159	0.962	0.38
			0.38	10.7	1.188	0.982	0.44
			0.39	10.0	1.216	1.003	0.48
3/7	1450	-0.6	0.40	14.1	1.100	0.886	0.39
			0.55	13.0	1.120	0.914	0.56

DATE	OBSERVATION TIME (Time of LLW)	TIDE	H_g	T	K_d	K_s	H'_o
			0.51	11.9	1.145	0.947	0.55
			0.59	10.8	1.180	0.978	0.68
3/8	1526	-0.4	0.55	10.0	1.216	1.003	0.67
			0.43	9.3	1.256	0.024	0.55
			0.51	8.4	1.325	1.052	0.71
			0.50	8.0	1.373	1.063	0.73
3/9	1556	-0.2	0.31	7.7	1.410	1.074	0.47
			0.26	7.6	1.425	1.078	0.40
			0.30	9.0	1.278	1.034	0.40
			0.37	10.8	1.180	0.978	0.43
3/10	1626	0.1	0.35	12.5	1.127	0.928	0.37
			0.65	12.8	1.119	0.920	0.67
			0.66	12.8	1.119	0.920	0.68
			0.90	14.4	1.095	0.878	0.87
3/11	1650	0.5	1.10	13.7	1.107	0.896	1.09
			0.65	12.6	1.124	0.926	0.68
			0.34	12.0	1.143	0.943	0.37
			0.55	11.4	1.159	0.962	0.61
3/12	1720	0.9	0.35	10.5	1.195	0.987	0.41
			0.30	12.3	1.132	0.935	0.32
			0.40	11.8	1.149	0.950	0.44
			0.45	11.5	1.160	0.959	0.50
3/13	1744	1.3	0.51	11.0	1.174	0.973	0.58
			0.54	10.6	1.189	0.985	0.63
3/14	0626	1.0	0.40	10.3	1.200	0.994	0.48

DATE	OBSERVATION TIME (Time of LLW)	TIDE	H_g	T	K_d	K_s	H'_o
			0.30	9.7	1.230	1.012	0.37
			0.19	9.2	1.264	1.028	0.25
			0.20	8.7	1.300	1.044	0.27
3/15	0708	0.9	0.13	8.9	1.284	1.037	0.17
			0.25	10.3	1.200	0.994	0.30
			0.24	13.9	1.103	0.891	0.24
			0.18	14.2	1.098	0.883	0.17
3/16	0802	0.7	0.20	13.6	1.108	0.898	0.20
			0.39	12.8	1.119	0.920	0.40
			0.42	12.2	1.136	0.937	0.45
			0.40	11.5	1.160	0.959	0.44
3/17	0902	0.6	0.38	10.9	1.179	0.976	0.44
			0.36	10.2	1.210	0.997	0.43
			0.37	9.4	1.250	1.021	0.47
			0.40	15.4	1.079	0.845	0.36
3/18	1008	0.4	0.34	15.1	1.086	0.861	0.32
			0.54	14.4	1.096	0.878	0.52
			0.54	13.7	1.107	0.896	0.54
			0.50	13.1	1.118	0.912	0.51
3/19	1120	0.1	0.46	12.2	1.136	0.937	0.49
			0.40	12.0	1.143	0.943	0.43
			0.30	11.9	1.145	0.947	0.33
			0.20	11.9	1.145	0.947	0.22
3/20	1220	-0.2	0.14	11.7	1.152	0.953	0.15
			0.35	11.2	1.168	0.967	0.40

DATE	OBSERVATION TIME (Time of LLW)	TIDE	H_g	T	K_d	K_s	H'_o
			0.40	10.4	1.199	0.991	0.48
			0.50	9.8	1.224	1.009	0.62
3/21	1314	-0.5	0.36	9.2	1.264	1.028	0.47
			0.42	8.8	1.291	1.040	0.56
			0.25	8.6	1.308	1.047	0.34
			0.24	8.4	1.325	1.053	0.33
3/22	1356	-0.7	0.12	8.3	1.337	1.055	0.17
			0.15	8.5	1.316	1.050	0.21
			0.10	9.0	1.278	1.034	0.13
			0.49	9.8	1.228	1.009	0.61
3/23	1438	-0.8	0.30	10.6	1.191	0.988	0.35
			1.00	5.2	2.320	1.085	2.52
			0.98	19.8	1.049	0.765	0.79
			1.05	4.0	5.245	1.033	5.69
3/24	1520	-0.6	1.31	5.5	1.970	1.091	2.82
			1.44	6.5	1.660	1.092	2.61
			1.12	7.0	1.533	1.086	1.86
			0.90	6.7	1.600	1.090	1.57
3/25	1556	-0.3	0.68	6.0	1.841	1.095	1.37
			0.61	15.7	1.079	0.848	0.56
			0.61	15.2	1.085	0.860	0.57
			0.60	14.9	1.088	0.865	0.56
3/26	1638	+0.3	0.60	14.4	1.095	0.878	0.58
			0.59	14.1	1.100	0.886	0.58
			0.54	13.8	1.105	0.894	0.53

DATE	OBSERVATION TIME (Time of LLW)	TIDE	H_g	T	K_d	K_s	H_o'
			0.49	13.5	1.110	0.920	0.50
3/27	1714	+0.9	0.46	6.5	1.660	1.092	0.83
			0.39	7.2	1.490	1.083	0.63
			0.38	7.0	1.533	1.086	0.63
			0.40	5.6	1.948	1.092	0.85
3/28	1756	1.6	0.37	5.4	2.000	1.090	0.81
			0.65	8.0	1.373	1.063	0.95
3/29	0702	-0.6	1.10	7.5	1.440	1.076	1.70
			1.60	6.2	1.760	1.094	3.08
			1.30	5.4	2.000	1.090	2.83
			1.35	14.2	1.098	0.884	1.31
3/30	0808	-0.6	1.00	13.0	1.119	0.914	1.02
			1.00	12.0	1.143	0.943	1.08
			0.86	11.0	1.174	0.973	0.98
			1.35	12.5	1.127	0.928	1.41
3/31	0914	-0.5	3.10	14.8	1.090	0.869	2.94

APPENDIX C

MEAN BEACH SLOPES

at the time of the beach profile observations on the date indicated.

DATE	$\bar{\alpha}$	DATE	$\bar{\alpha}$	DATE	$\bar{\alpha}$	DATE	$\bar{\alpha}$
2/1	.0631	2/16	.0648	3/3	.0541	3/18	.0658
2/2	.0559	2/17	.0614	3/4	.0549	3/19	.0591
2/3	.0551	2/18	.0615	3/5	.0565	3/20	.0632
2/4	.0463	2/19	.0614	3/6	.0565	3/21	.0629
2/5	.0572	2/20	.0675	3/7	.0566	3/22	.0571
2/6	.0620	2/21	.0593	3/8	.0568	3/23	.0592
2/7	.0631	2/22	.0587	3/9	.0567	3/24	.0526
2/8	.0664	2/23	.0630	3/10	.0535	3/25	.0598
2/9	.0533	2/24	.0587	3/11	.0586	3/26	.0599
2/10	.0546	2/25	.0537	3/12	.0603	3/27	.0564
2/11	.0518	2/26	.0548	3/13	.0609	3/28	.0591
2/12	.0523	2/27	.0544	3/14	.0596	3/29	.0668
2/13	.0605	2/28	.0539	3/15	.0611	3/30	.0516
2/14	.0686	3/1	.0553	3/16	.0617		
2/15	.0655	3/2	.0615	3/17	.0628		

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Professor Warren C. Thompson Department of Oceanography Naval Postgraduate School Monterey, California 93940	5
4.	Ensign J. D. Williamson 1727 Caddell Lane Norman, Oklahoma 73069	2
5.	Professor E. Thornton Department of Oceanography Naval Postgraduate School Monterey, California 93940	1
6.	Department of Oceanography Naval Postgraduate School Monterey, California 93940	3
7.	Oceanographer of the Navy The Madison Building 732 N. Washington Street Alexandria, Virginia 22314	1
8.	Dr. Ned A. Ostenso Code 480D Office of Naval Research Arlington, Virginia 22217	1
9.	Evelyn L. Pruitt, Director Geography Programs, Code 414 Office of Naval Research Department of the Navy Washington, D. C. 20360	1
10.	Commanding Officer Fleet Numerical Weather Central Monterey, California 93940	2

	No. Copies
11. Coastal Engineering Research Center 5201 Little Falls Road, N. W. Washington, D. C. 20016	1
12. Mr. Charles Fisher, Chief Coastal Engineering Branch U. S. Army Corps of Engineers P. O. Box 2711 Los Angeles, California 90053	1
13. Commanding Officer San Francisco District U. S. Army Corps of Engineers 100 McAllister Street San Francisco, California 94102 Navigation and Shoreline Planning Section Library	1
14. Coastal Engineering Branch Planning Division U. S. Army Engineering Division, South Pacific 630 Sansome Street San Francisco, California 94111	1

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

ORIGINATING ACTIVITY (Corporate author) Naval Postgraduate School Monterey, California 93940	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

REPORT TITLE

Onshore-Offshore Sand Transport on Del Monte Beach, California

DESCRIPTIVE NOTES (Type of report and, inclusive dates)

Master's Thesis; September 1972

AUTHOR(S) (First name, middle initial, last name)

John David Williamson

REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
September 1972	66	22

. CONTRACT OR GRANT NO. . PROJECT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

. ABSTRACT

Daily sand volume transport values were calculated for a selected beach profile during a two-month period. Wave data were recorded continuously directly seaward of the profile. Tide effects were largely filtered out by use of a lunar day (24.8 hour) sampling interval.

Offshore sand transport occurred in isolated events of one to two-day duration, and had a maximum value of 132.5 cubic feet/foot of beach width/lunar day. Onshore transport occurred over longer intervals of up to seven days, and had a maximum value of 47.0 cubic feet/foot/day.

Onshore-offshore transport over a 24.8 hour period depends, to a first approximation, on the mean wave steepness incident upon the beach and the initial beach slope for the period. If the initial beach slope is greater (less) than the equilibrium slope associated with the existing wave conditions, or if the profile is initially at equilibrium and the wave steepness increases (decreases), sand will be moved offshore (onshore). The closer to equilibrium the beach is, the smaller the transports are.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
BEACH EROSION AND ACCRETION						
MONTEREY BAY						
OFFSHORE - ONSHORE SAND TRANSPORT						
WAVE EFFECTS ON BEACHES						

Thesis
W6252 Williamson 138388
c.1 Onshore-offshore sand transport on Del Monte Beach, California.